The Effect of Wind Generation on Wholesale Electricity Prices in Ireland

Rónán Kernan
Queen's University Belfast
Northern Ireland

Xueqin (Amy) Liu
Queen's University Belfast
Northern Ireland

Seán McLoone
Queen's University Belfast
Northern Ireland

Brendan Fox
Queen's University Belfast
Northern Ireland

Abstract—**The integrated electricity sector on the island of Ireland has ambitious plans for 37% penetration of wind power by 2020. Wind generation has no marginal cost, and so high penetrations of wind could be expected to reduce the cost of electricity. An understanding of the effect of wind generation on electricity prices would allow the design on effective price-based Demand Response (DR) schemes to support wind generation. Normally, the marginal unit on the Irish power system is gas-powered, and thus gas prices have a strong effect on electricity prices. This work investigates the relationship between wind generation and electricity prices in Ireland in recent years by first controlling for the effect of gas price variation. The varying impact of wind power at different levels of demand is explored, and an estimate is made of the reduction in energy costs from increasing levels of wind generation.**

I. Introduction

Positioned on the edge of the Atlantic Ocean and thus subject to a strong predominantly Westerly wind, Ireland is ideally placed to make use of wind for power generation. Although composed of two political jurisdictions (the Republic of Ireland and Northern Ireland), the island's power system (and electricity market) operate on an all-island basis. Both jurisdictions have a target to produce 40% of all electricity from renewable sources by 2020, of which 37% is to come from wind [1]. Installed capacity of wind generation rose from 145 MW in 2002 to more than 3 GW in 2016 [2]. Peak demand was approximately 6.4 GW in 2016, with an average demand of 4 GW [3]. Table I shows how installed capacity and wind capacity have changed over time. Wind generation data was taken from EirGrid's Smart Grid Dashboard [3], while installed capacity data is from [2].

In the Irish Single Electricity Market (SEM), generators bid on the basis of their marginal cost, with the single most expensive in-merit generator setting the System Marginal Price (SMP). Each day is split into 48 30-minute SMP periods. An estimate of SMP is provided on the basis of demand and wind forecasting (Ex-Ante 1 or EA1), while the cost of system constraints and balancing are factored into the final SMP value (Ex Post 2 or EP2) which is made available 4 days after the day in question [7] [10]. Wind generation is taken to have no marginal cost and is thus 'price taking'. It follows that increased penetrations of wind generation would reduce the requirement for more expensive generators and thus reduce SMP - this is the 'merit-order effect' of wind generation. While it has been shown that this effect does exist, different approaches have been taken to quantify it.

A drawback of wind generation is its variability - it cannot be dispatched, only forecasted and curtailed. One means of mitigating this variability is Demand Response (DR), where loads are controlled or encouraged to coincide their demand with periods of increased wind generation. This could be done by offering load an electricity tariff based on wind generation itself or, if a correlation can be shown between periods of low SMP and high wind generation, a tariff based directly on the SMP. This was explored by the authors in previous work [12], where it was found that by scheduling a flexible load on the basis of SMP the load not only saved money but also increased the proportion of consumed electricity coming from wind. However, the uptake of wind generation was found to be significantly greater when load was scheduled on the basis of wind generation itself compared to scheduling on the basis of SMP. This showed that while there was some relationship between wind and price, there were other factors with a strong influence on SMP.

Wurzberg et al. in [6] found that each additional GWh of price-taking renewable generation reduced prices in the German-Austrian electricity market by €1/MWh using data from 2010-2012. Their analysis found that smaller power systems experienced a greater merit-order effect than larger ones, with wind power expected to reduce prices to a greater extent in Ireland than in large markets such as Germany and Austria.

Swinand et al. in [7] analysed wind data from the SEM from 2008 - 2012. Their results found that for each 1% increase in wind generation, SMP was reduced by approximately 0.06% - a very weak correlation, although wind generation was significantly lower that it is at present during the time period investigated. In [13], Denny et al. modelled the impact of wind generation on the 2009 Irish power system, when wind generation had an installed capacity of 1264 MW, providing 10.5% of Ireland's electricity [14]. They found that wind generation reduced the ex-post SMP by 4 - 5.4% versus a zero wind scenario and that there was a linear relationship between wind generation and SMP. This relationship, however, was weaker than that between price and demand, or price and fuel costs.

Public opinion in Ireland has generally been in favour of wind power [11], but debate continues on its economic impact, particularly on the issue of whether the savings from reduced price outweigh the additional cost of support mechanisms. The Sustainable Energy Authority of Ireland found that the avoided cost of importing fossil fuels in the Republic of Ireland due to wind power in 2012 was €242 million, while the subsidy paid to wind generators in the Republic of Ireland was €55 million [4]. In the Spanish power system (which also has significant renewable

TABLE I: Growth of wind power in Ireland

Year	Installed Cap. (MW)	Av. Wind Gen. (MW)	Av. Cap. Factor (%)	Av. Wind Pen. (%)
2012	2093	606	29%	14%
2013	2325	698	30%	17%
2014	2646	730	27.6%	19%
2015	3021	940	31.1%	23%
2016	3320	863	26%	22%

penetrations), de Miera et al also found that the reduction in wholesale prices from renewable energy was greater than the increased costs due to support mechanisms [5]. An IWEA report in 2011 estimated SMP reductions of up to 17% from wind penetrations of 45% in 2020, with savings significantly outweighing the cost of subsidies [16]. There is thus significant evidence that not only does increasing wind generation reduce CO_2 emissions and reliance on fuel imports but that, even with a subsidy scheme, it reduces overall costs as well.

In Ireland, as wind power penetrations have increased, it has become necessary to reassess the impact of wind on electricity prices. While the impact of wind on electricity prices has been considered before, such an analysis has not been carried out at wind penetrations as high as they have reached in recent years. In this work, the correlation between wind penetration and SMP in the Irish SEM was investigated for the years 2014 - 2016, where wind penetrations had increased significantly compared to previous years (see Table I). In [15], O'Flaherty et al. could not find a definite relationship between SMP and wind generation but did find a very strong correlation between the price of gas and SMP, a conclusion echoed in [16].

In this study, the effect of the gas price on SMP was neutralised, enabling the correlation between SMP and wind penetration to be examined (section II). The seasonal effect of wind on SMP was investigated in Section III. An estimation of the overall financial impact of high wind penetrations on SMP was made in Section IV, and the impact of wind on SMP at different levels of demand considered in Section V.

II. Correcting for Gas Price

Gas-fired power generation is the single largest contributor to the Irish power system by fuel source, providing 42% of all electricity in 2015 [17]. Because of this, and its relative flexibility in responding to changes in demand, gas is normally the fuel source of the marginal unit in the SEM [16]. As found in [15], SMP has been very closely correlated to the UK's National Balancing Point (NBP) gas price, since (until the recent activation of the Corrib gas field in County Mayo) all of Ireland's gas came from the UK. This can be seen in Fig. 1, comparing daily NBP gas prices and daily average SMP for the period 2010-2016. Gas price data were taken from the ICE [18].

In order to properly understand the effect of wind generation on SMP, it is thus necessary to correct for the effect of gas

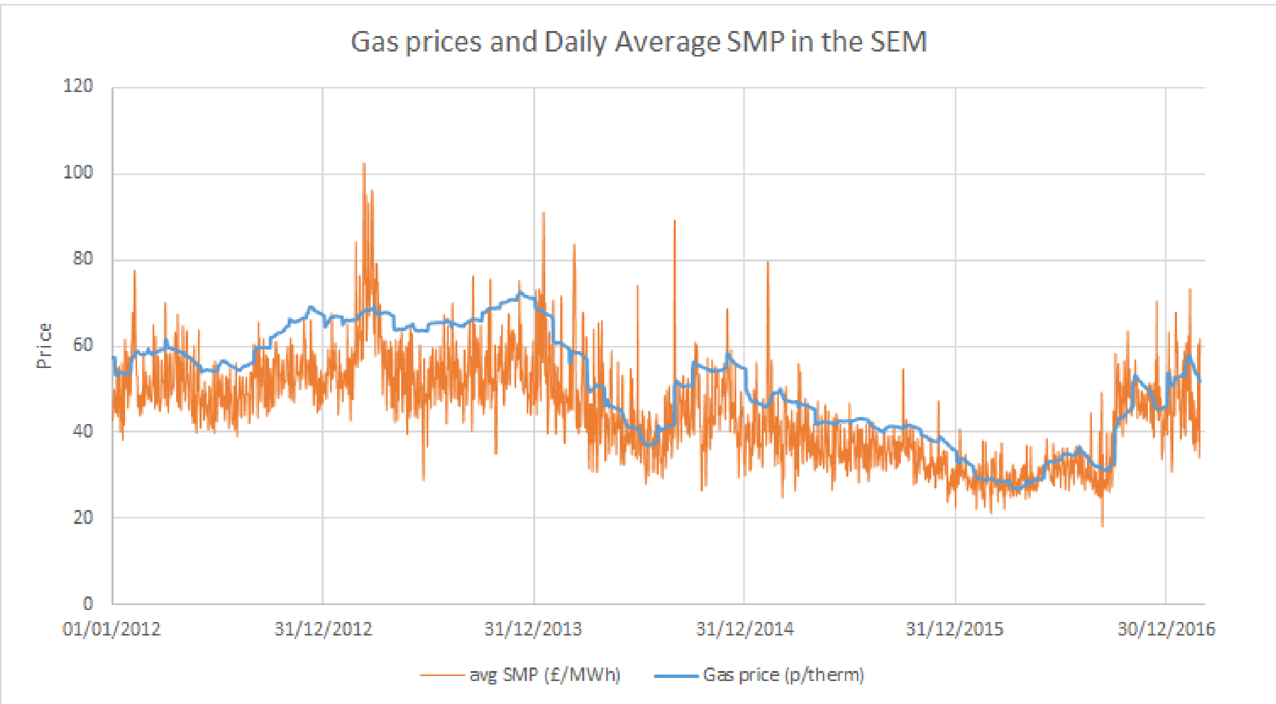
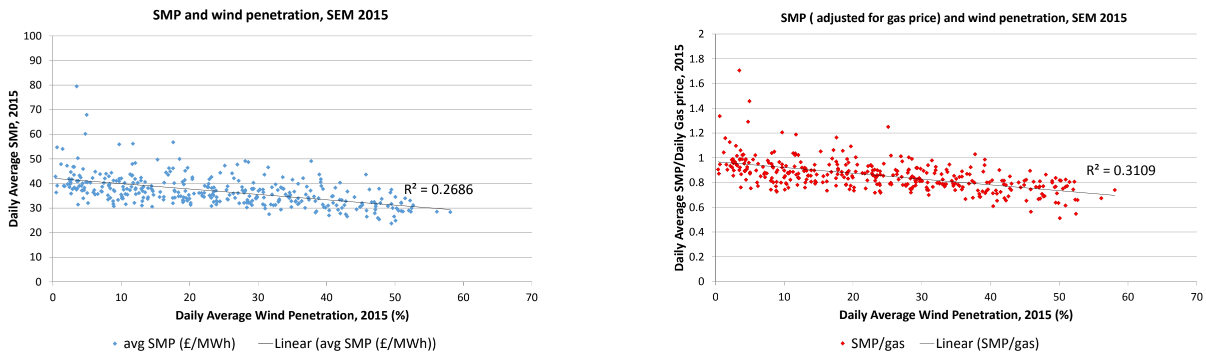


Fig. 1: *NBP gas prices and SEM daily average SMP, 2010-1016. P <0.001. The divergence between the curves in March 2013 corresponds to a period of exceptionally low temperatures.*



a

b

Fig. 2: *Daily average wind penetration and (a) SMP and (b) gas adjusted SMP, 2015*

TABLE II: Correlation between wind penetration and SMP

Year	SMP R^2	SMP/Gas R^2
2014	0.0728	0.3516
2015	0.2686	0.3109
2016	0.0484	0.2214

price variation. To do this, the average SMP for each day was divided by the gas price for that day to give an adjusted value which eliminated the effect of the variation in gas price as per eqn. 1.

$$P_{adj} = \frac{\sum_{i=1}^{48} P_i}{48 G_d} \quad (1)$$

Where i is a 30-minute period of a given day, P is SMP, and G_d is the daily NBP gas price.

Fig. 2 shows daily average wind penetration plotted against daily average and gas price adjusted EP2 SMP for 2015, while Table II shows a summary of the R^2 correlation between wind penetration and SMP and wind penetration and gas price adjusted SMP for 2014 - 2016. In each case, the correlation between wind penetration and SMP increased significantly once gas price had been corrected for, as can be seen from the R^2 values in the figures. In all cases, $P < 0.001$, but was lower for the adjusted SMP in each instance. The lowest correlation was seen in the unadjusted 2016 data which can be explained by the high degree of variation in gas price that year, as can be seen in Fig. 1.

III. Seasonal Effects

In Ireland, electricity demand is significantly higher in winter than in summer, due to increased lighting and heating requirements. Traditionally, this has led to higher operating costs in winter, as the increased demand has led to more expensive generators being in merit more often. However, wind generation is also higher during the winter months as more frequent Atlantic storms bring high winds to the island. Fig. 3 shows daily average SMP plotted alongside daily average wind penetrations for the year 2015, as well as seven day moving averages of both for clarity. High wind events happened more often at the beginning and end of the year - while the average demand was highest.

Fig. 4 shows seasonal averages of demand, gas price-adjusted EP2 SMP (multiplied by four for easier legibility) and wind generation and penetration for 2014-2016. This clearly shows that the higher wind penetrations in winter went some way towards offsetting the additional load compared to summer. Once the gas price was adjusted for, there was no discernable correlation seen between the time of year and average EP2 SMP for the years studied.

IV. Estimating Cost Reduction

High penetrations of wind power should reduce power system operating costs as there is no associated marginal cost. This should displace low-merit generators.

It would be possible to estimate the reduction in operating cost of the Irish system from the expansion of wind generation by assuming similarly low wind penetrations occurred throughout the year to those seen in the bottom quartile of windy days in that year. However, because of the uneven seasonal distribution of high and low-wind days discussed in Section III, this would not give a good representation of the year as it would give unrepresentative weighting to summer days. Despite the fact that no correlation between time of year and SMP was seen in Section III, a weighting was applied to the seasonal data in the top and bottom quartiles in order to correct for this uneven distribution. The British power system, with a

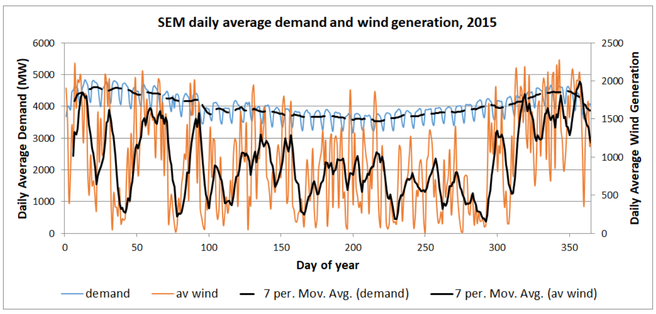


Fig. 3: *SMP, daily average wind generation (with 7-day moving averages), 2015*

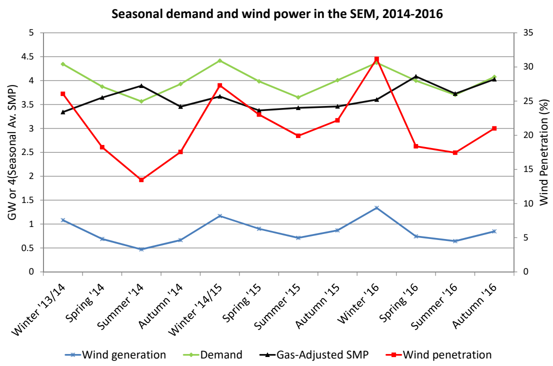


Fig. 4: *Seasonal average demand, wind generation and penetration and seasonal average SMP in the SEM, 2014-2016*

near-identical climate to Ireland, has a significantly lower average wind power penetration (11% in 2015 [19]) but displays strong seasonal variation in market price [20]. It may be the case that the additional wind generation seen on the Irish power system offsets this seasonal effect. In this analysis, it was thus assumed that a degree of seasonal variability would be seen in SEM SMP prices were wind penetrations lower.

It should be noted that this approach would not allow a cost comparison with a zero wind generation scenario, but would give an indication of the costs that might be seen on the current Irish power system if the aggressive expansion of wind generation of the last 15 years had not occurred. This approach was taken as there were not enough data for periods with less than 1% wind penetration from which results could be extrapolated.

In order to account for the skewed seasonal distribution of days in the bottom quartile of windy days for each of the years investigated, the bottom quartile was split into seasonal sets:

$$B = \sum_{s=\text{Wi}}^{Au} J_s \tag{2}$$

B is bottom quartile of windy days, J_s being the set of days in bottom quartile for a given season: Wi[nter], Sp[ring], Su[mmer] and Au[tumn].

For balanced results, each season should have equal weighing. A weighting factor (Q_s) was calculated for each season to scale it to one quarter of the total data:

$$Q_s = \frac{B}{4J_s} \ \forall s \tag{3}$$

The average operating cost per market period (V_s) was then found by multiplying the average seasonal demand (D_s) by the seasonal average gas-adjusted SMP (P_s) (for all seasons):

$$V_s = D_s P_s \ \forall s \tag{4}$$

The corrected average demand was then found and compared to the actual average demand for the year (D_a) to produce a balancing factor (F) which would ensure the same average demand for the analysis as in reality:

$$F = \frac{\sum_{s=\text{Wi}}^{Au} (Q_s P_s)}{\sum_{s=Wi}^{Au} D_a} \tag{5}$$

The products of seasonal weighting and average value per period were added together and divided by the sum of all weightings and balancing factor to find the annualised average value (A_b) per period:

$$A_b = \frac{\sum_{s=\text{Wi}}^{Au} (Q_s V_s)}{F \times \sum_{s=\text{Wi}}^{Au} Q_a} \tag{6}$$

$$\frac{d}{dA} = \frac{A_b - A}{A} \tag{7}$$

Table III shows the results of this analysis for the years 2014-2016. The results seen in Table III are significant. They do not take into account how the sums invested in wind power might have otherwise been spent had wind power not been developed, nor do they account for some factors affecting demand such as weekly patterns, and as such are likely to be a slight overestimation in this respect. However, this is mitigated by the fact that this analysis did not compare the current wind power configuration with a zero-wind scenario, in which higher savings could reasonably be expected. Thus these savings give a good estimate of how much more expensive the power system would be if wind penetrations were much lower than they currently are. The savings seen compare favourably with the subsidy (approximately £100 million in 2015) paid to wind generators seen in [21].

V. Narrow Band Analysis

SMP is determined by the most expensive in-merit generator required to fulfil demand during a given 30-minute period. It follows that all periods across a given year with demand within a specified narrow band (disregarding significant changes to the available plant, neglecting wind power and controlling for fuel price variation) would have the same generation plant committed and thus very similar (if not the same) SMPs. The impact of wind generation on the merit-order effect (and thus SMP) can be analysed by comparing wind generation and SMP across a number of these narrow bands of demand data.

This procedure was carried out on data from the Irish power system for 2014-2016. Each year's demand data was placed into 50 MW bins, from the smallest to the highest demand for that year. EP2 was adjusted for variation in gas price, and the adjusted SMP was plotted against wind generation for all the datapoints within each bin. Linear regression gave the lowest standard error of the regression techniques tried.

TABLE III: Estimated increase in operating costs if wind penetrations were approx. 5%, 2014-2016

Year	Actual Wind Pen.	Simulated Wind Pen	Price increase	Approx cost difference
2014	19.0%	4.8%	12.5%	£198m
2015	23.8%	5.8%	13.6%	£179m
2016	21.2%	6.2%	8.0%	£79m

Applying linear regression to the data allowed the degree of correlation between SMP and wind to be calculated using R^2 values. Figure 5 shows the R^2 values for all 50 MW demand bands in 2014-2016. Only demand bands with at least 100 data points were included in this analysis. Table IV shows the average R^2 value for each of the three years.

Clearly, even when gas price variation has been accounted for and demand data separated into narrow bands to control for the merit-order effect, wind generation does not account for more than approximately 18% of the variation in SMP. However, there was a clear and consistent correlation between wind generation and SMP in the years investigated. Interestingly, the effect of wind on SMP seemed to weaken markedly in 2016. This is consistent with the low capacity factor of wind seen in that year (see Table I), likely due to lower than average wind speeds. 2016 was the first year in recent memory where average wind generation decreased despite increasing capacity. Once the data become available, analysis of future years will be necessary to establish whether 2016 was a one-off or a sign of a future trend.

An estimate of price reduction from wind power can be made from taking the narrow band encompassing the average demand across the years studied (3990 MW) and plotting wind generation against SMP, as per Fig. 6. From this figure, for an average level of wind generation during a period with an average level of demand, wind generation can be said to reduce SMP by approximately £6. Multiplying by average demand (3990 MW) and the number of trading periods in a year (8760) gives an approximate cost reduction of £209 million per year - a figure similar to those seen in Table III, and greater subsidy of approximately £100 million paid to wind generators in 2015 [21]. If gas prices were constant, the same analysis suggests that SMP was approximately 18%

TABLE IV: Average R^2 values, all demand bands with >100 samples, 2014-2016

Year	Average R^2 Value
2014	0.1899
2015	0.1774
2016	0.1019

lower in the years studied than it would otherwise be. Fig. 7 shows the gradient of the linear regression applied to the 50 MW demand bands for each of the years in 2014-2016. It can clearly be seen that the gradient of the fit line was steeper for higher demand bands. This is significant as it suggests that wind generation is more effective at reducing SMP when demand is high. This is consistent with the merit order effect - at high demand, more expensive generators are in- merit; thus, when wind coincides with high demand, it displaces more expensive generation and reduces the SMP to a greater extent than it would at low demand.

VI. Conclusion

Wind generation in Ireland provides a significant proportion of the island's electricity, with further expansion anticipated in the near future. Wind power presents challenges to power system and market operators as well as public opinion, but by understanding the effect of wind generation on operating costs in a liberalised energy market, an economic case can be made.

Due to gas generation providing the predominant marginal plant in Ireland, wholesale electricity closely follow variations in the price of imported gas. This may change as the Corrib gas field off the Western coast is developed and Ireland achieves a degree of independence in gas supply, but

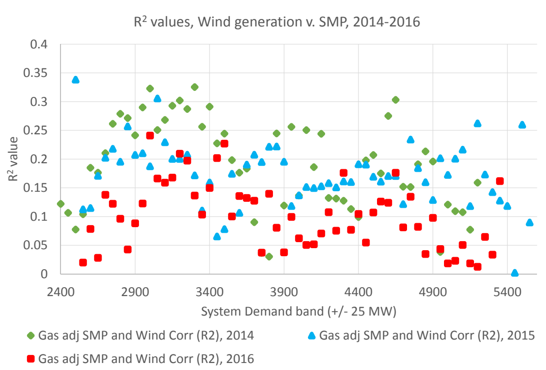


Fig. 5: *R^2 values, all demand bands with >100 samples, 2014-2016*

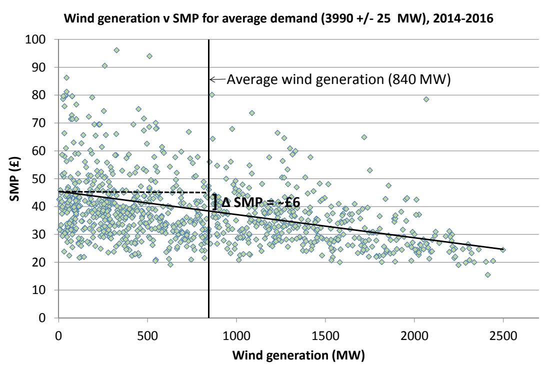


Fig. 6: *Wind generation plotted against SMP for the average demand in 2014 - 2016. The vertical line shows average wind geneeration during that period.*

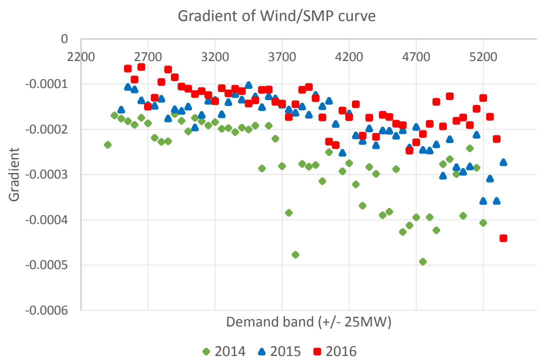


Fig. 7: *Gradient of best fit line, all demand bands with >100 samples, 2014-2016*

gas is likely to remain the marginal plant on the Irish power system for the foreseeable future. Wind power, nonetheless, has a significant secondary effect on wholesale electricity prices, and once variations in gas price have been corrected for, a clear reduction can be seen in electricity price on windy days compared with non-windy days, despite the fact that this frequently coincides with higher electricity demand in winter. The effect of wind on electricity prices also increases in line with demand, as at high demands wind generation displaces more expensive conventional generation.

The large-scale development of wind generation in Ireland can be seen to have reduced system operating costs significantly, with savings greater than the subsidies offered to encourage investment, even before taking into account the avoided expenditure on CO_2 emissions credits. There is thus a strong economic case for continued development of wind power in Ireland. It should however be noted that there is an increased infrastructure cost associated with wind generation, as wind turbines are generally located far from centres of population and thus would require reinforcement of the transmission system. High penetrations of wind power could thus be said to reduce the wholesale cost of electricity but increase its transmission costs. Since customer electricity prices are made up of a combination of both, the savings seen here would not necessarily translate to equally high savings for end-users. However, investment in wind power reduces the requirement for investment in other forms of power generation. Wind turbine construction costs have fallen consistently, and clustering of turbines into large wind farms reduces the associated infrastructure cost. Even without wind generation, grid reinforcement would nonetheless be necessary to accommodate growth in demand. The savings seen here could be expected to increase as wind penetrations continue to grow in the coming years. As the principle of diminishing returns is likely to apply to the deployment of wind generation then it will be necessary to revisit the cost-benefit analysis in order to find the optimum contribution of wind to the Irish power system.

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